DEVELOPMENT OF THE CONTROL SYSTEM FOR ELECTRIC ACTUATOR WITH BLDC MOTOR

Jiří Toman*, Vladimír Hubík*, Vladislav Singule*

The aim of this article is to inform reader about the development steps and practices which were used during the development of a control system of a fuel metering pump. The aim of this development was to design a control system for a BLDC motor in accordance with rigid aviation standards and verify new development practices and tools allowing faster and simpler certification. The development covers such steps as definition of first requirements, preliminary design, system modelling and simulation, detailed design, verification and testing. Given description introduces reader to mandatory practices and procedures which are obligatory for successful certification of developed control systems. In addition, the first results measured on an evaluation sample are presented.

Keywords: *BLDC motor, dSpace, fuel metering pump, control system, COTS, simulation and modeling, power electronics, H-bridge, sensor-less control*

1. Introduction

Based on previous experience an each development of a control system starts with definition of requirements and system modelling. A mathematical model describing all parts of the control system together with a system under control gives to developers an exact idea about system behaviour, reactions and ability to verify different control strategy and algorithms in early stage of development. In addition, the control system can be tested by means of hardware in the loop simulation, e.g. using tool such a dSPACE, completely without any previous hardware design. This is a considerable advantage since team could precede many mistakes, dead ends and even damage of the first evaluation samples. Unquestionably, these are benefits that considerably decrease development time and costs.

2. Model of the control system

Mathematical model of the control system with controlled BLDC motor consists of three basic parts: electrical, mechanical and sensing. The model was designed to implement as many as possible of known motor parameters given by its producer and also as many parameters which describe the control system in appropriate detail to closely match real conditions. It is beyond the scope of this article to describe the whole mathematical model in detail; inquisitive reader can find it in [1], [2] and [6].

The important tracked values are amplitude of induced voltages in particular windings, winding currents, rotor position and acceleration of the rotor. An example of traced values is depicted in Fig. 1.

* Ing. J. Toman, Ing. V. Hubík, doc. Ing. V. Singule, CSc., Institute of Production Machines, Systems and Robotics, Faculty of Mechanical Engineering, Brno University of Technology

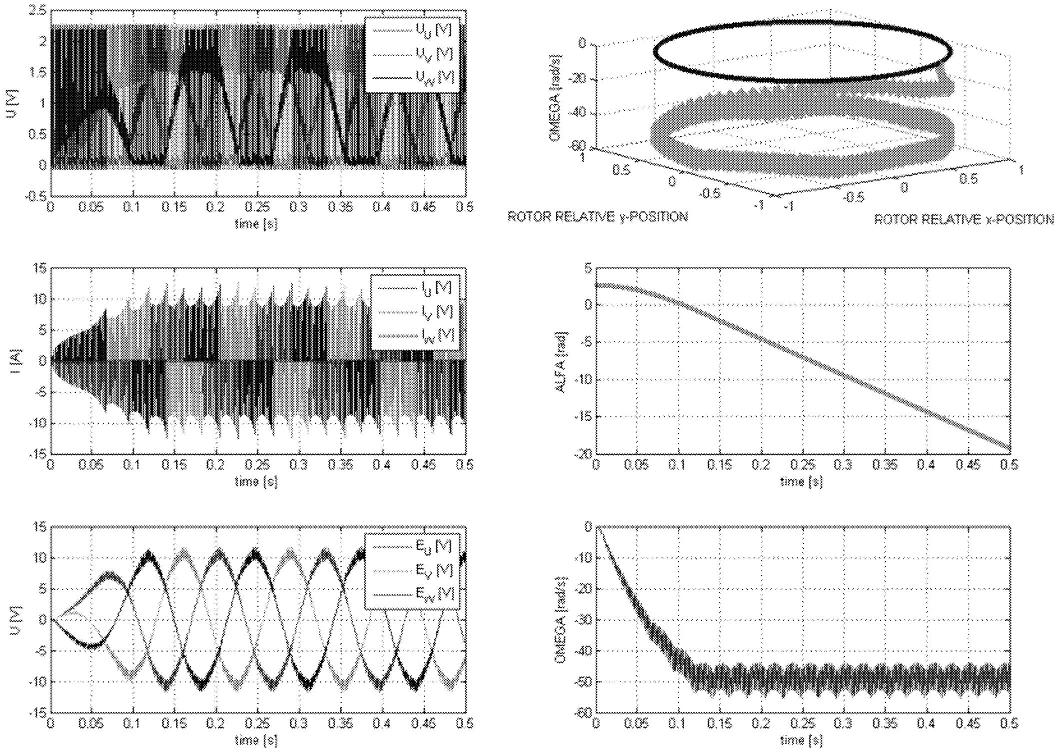

Fig.1: Example of the control system simulation results

The starting phase of rotor was chosen as the most important since this phase is the most critical during operation of the FMP. Therefore many algorithms were tested to achieve fast reaction and smooth acceleration at reasonable current flow level. Values provided by simulations of the control system were used in hardware design which was next step of the project.

3. HW design of control system

The control system is designed as modular and it consists of three parts that can be interchangeable according to customer needs. The three basic modules are Control and Communication Unit (CCU), Power Electronics Unit (PEU) and I/O Unit (IOU). The control system architecture is shown in Fig. 2.

3.1. Control and communication unit

Main microcontroller is placed on Control and Communication Unit (CCU). The CCU is replaceable according to application performance requirements and architecture of control system. Core of the CCU is created by a multipurpose microcontroller (MCU).

The CCU has unified interface for all analogue and discrete signals that are used for control and communication with other control system modules. Using unified interface enables replacement of the CCU in case of system enhancement or maintenance.

Electronic control system for the FMP can provide selected information of its internal states and measured values to higher level control system via an internal communication

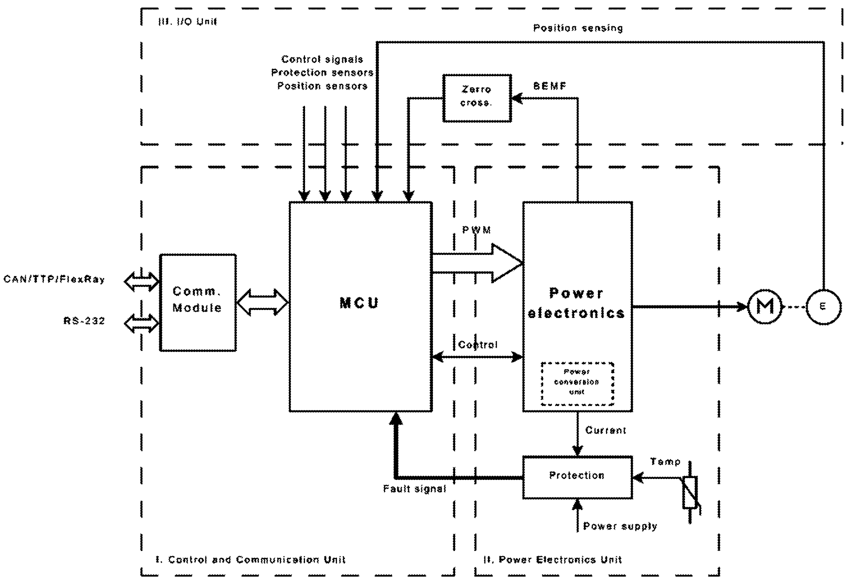

Fig.2: Architecture of the electronic control system for EHA/EMA actuators

network. The higher level control system can be a Flight Control Computer (FCC) or a multifunction avionic display placed in the pilot's cockpit.

3.2. Power Electronics Unit

The Power Electronics Unit (PEU) consists of full H-bridge that is created by six power switching transistors. Motion of the BLDC motor is controlled by switching power supply to particular coils of the BLDC motor.

An integral part of the PEU is Protection module that measures temperature, current and voltage on the BLDC motor. In case of any parameter exceeds a limit value, protection module generates fault signal that enters into the MCU. Detection of the fault signal causes disconnecting of load from the power supply source.

3.3. I/O Unit

BLDC motor signals/sensors

Depending on actual configuration, electronic control system could operate either in sensor or sensor-less mode.

In sensor mode signals from Hall sensors are used as feedback. These sensors are usually mounted inside the BLDC motor by its producer. These signals are triggered and used as inputs into the control MCU.

Sensor-less control mode operates on principle of sensing induced voltage caused by Back Electro Motive Force (BEMF) on one of three BLDC motor phases. Feedback is extracted by the means of BEMF and zero-cross detection.

Functionality and safe operation of actuator is ensured by monitoring of selected parameters and restricting actuator's fault operation. If one or more of signals exceed its limit value, the fault is detected and appropriate action is taken.

3.4. Evaluation sample

The control system was designed to fit requirement of mounting into the FMP to create a monolithic box with an explosion-proof design. Development runs in accordance with aviation standards [3], [4] and [5]. The first evaluation sample is shown in Fig. 3.

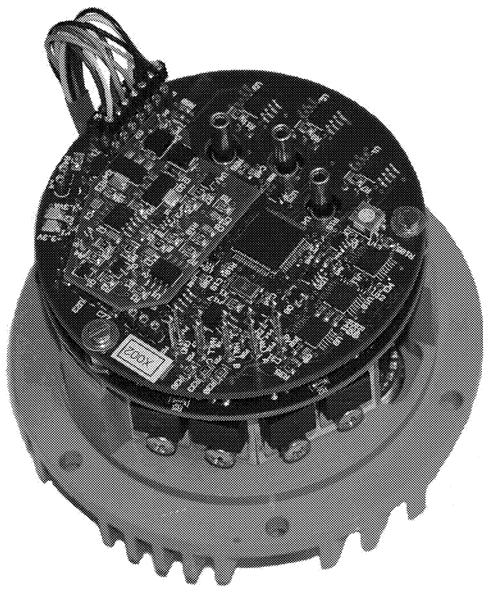

Fig.3: The first evaluation sample of the control system for FMP

Electronics of the control system is designed in a custom tailored shape with logical partitioning according to performed functions. Logical partitioning to control, power electronics and sensing board brings also the advantage of custom configuration and much simple service.

4. Software design of control system

The main aim that was taken into consideration is that control system had to be portable and easy to implement on a common 16-bit MCU. Final control system is written in the C programming language and is implemented into a Microchip dsPIC MCU.

Algorithms are designed with respect to high criticality of the applications, therefore no artificial methods or fuzzy control algorithms could be used. Requirements on high reliability also limit the code complexity, thus simple but efficient software algorithms are used where ever it is possible.

Software design was preceded by detailed decomposition of system requirements, interface definitions, data flow and control flow. These requirements and definitions expressively determined final form of source code.

Therefore their thorough evaluation was extremely important for design of control algorithms. Proper definition and evaluation simplified software development cycle and eliminated errors caused by further implementation of additional functions.

The control algorithm is designed according to the flowchart that is shown in Fig. 4. The algorithm consists of initialization part, motor start-up, closed loop control and interrupts service routines.

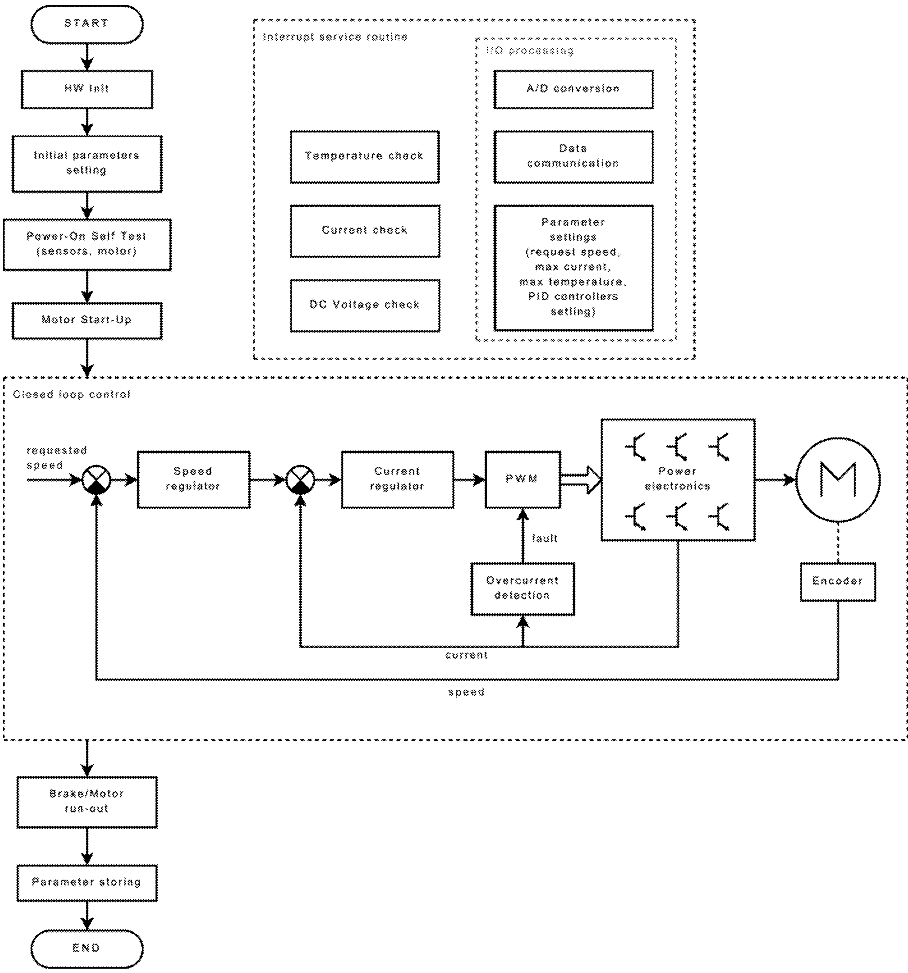

Fig.4: Concept of the control system software design

4.1. Initialization

Initialization part serves for initial hardware set-up, parameter setting and power-on self test. During this stage all the parameters and values are checked against the standard values. In case of abnormal value or malfunction the control system issues warning and tries to re-initialize hardware again.

4.2. Motor start-up

In critical applications, it is necessary to ensure correct start-up of the motor. Thus, many simulations had been done before implementing the control algorithm into the controller. The motor start-up algorithm ensures reliable start-up of different types of BLDC motors.

4.3. Closed loop control

After initialization and motor start-up sequence, the control algorithm switches into the closed loop control. Closed loop control algorithms consist of two nested PID controllers – speed controller and current controller.

The current regulator sets desired value by means of PWM. It compares a desired value from superior speed regulator and measured current through the BLDC and sets output value upon their variance.

The speed regulator sets desired value for the current controller. Actual rpm speed could be measured by Hall sensors or using Back Electro-Motive Force (BEMF).

4.4. Interrupt service routines

Interrupt service routines serve for performing repeating tasks that evaluate critical values, such as power electronics temperature, current flowing into the BLDC motor, DC bus voltage, etc.

Separate interrupt service routines also serve for Input/Output processing and measurement. These especially involve:
- A/D conversion,
- data communication (via CAN or RS-232 data interface),
- parameter setting (parameter setting is based on data communication commands).

5. First evaluation sample test results

To evaluate performance of the control system and design electronics, two types of evaluation test benches were used. Firstly, an in-house developed evaluation test bench. The first measurements and simulated dynamic testing were performed on this evaluator; different control algorithms were tested and controller variables were set. Then the control system electronics was mounted on the FMP and performance tests were performed on an evaluation mock-up platform that simulates a real fuel circuit. These test were performed with help of an external company and the main interest were put on start and stop sequences of the FMP.

Start sequence of the FMP is shown in Fig. 5.

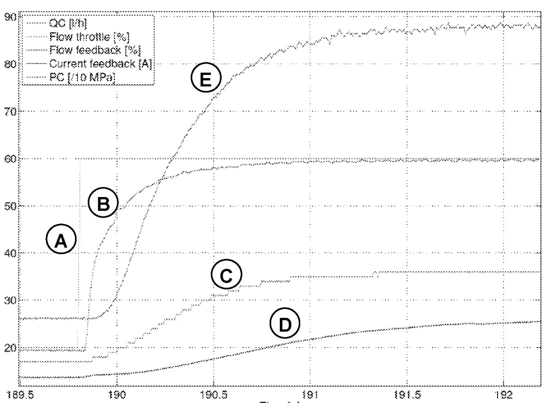

Fig.5: FMP starting sequence measured on the fuel circuit simulator

In Fig. 5 the green line (A) represents requested value of fuel flow. The measurement monitors reaction of the system on setting requested value of fuel flow to 60 %.

The red line (B) represents fuel flow which is measured and computed by the control electronics. It is evident, that measured fuel flow gradually increases up to the requested value without overshoot.

The brown line (E) indicates real fuel flow in the system measured by an external sensor. The real value of the fuel flow traces is measured by electronics with a slight time delay and slower increase which is due to physical characteristics of the mock-up system (gradual increase of fuel pressure, time delays caused by fuel flow through system).

The pink line (C) represents pressure in the system and the blue line (D) indicates peak current values during PWM cycle as were measured by electronics on the H-bridge.

Stop sequence of the FMP is shown in Fig. 6.

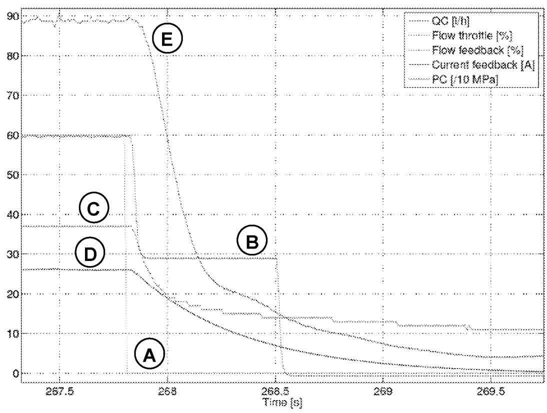

Fig.6: FMP stopping sequence measured on the fuel circuit simulator

In Fig. 6 colour representation of individual measured values stays the same as in Fig. 5. After setting the desired value of fuel flow to zero, the control system of the FMP stops the BLDC motor and fuel flow gradually decreases to zero. Step shape of the fuel flow (red line (B)) measured by electronics is caused by overflow of timer which is used for measurement of motor rpm. The fuel flow measured by external sensor indicates gradual decrease although the BLDC motor is not running. This short term decrease of the fuel flow is due to inertial flow inside the mock-up system.

6. Conclusions

The development and certification of any new equipment for aerospace industry requires – except the best quality, performance, safety and reliability – also compliance to strong regulation standards. Use of COTS components and tools seems to be one of possible choices to reduce the development time and costs.

Use of COTS components and development tools enables faster development cycle with ability of modelling and preliminary design in the early stage of project. Results from this stage can be used as a basis for hardware and software design which saves additional costs and accelerates process very rapidly.

Development procedures described in this article indicate that they can bring significant improvements in performance, safety and reliability of the control system along with reduction of development time and costs.

Acknowledgment

This work is supported by project of specific research, Brno University of Technology, 'Environmental and safety aspects of the development, manufacture and operation of machines'. Hardware and software development and physical modules were realized and project was supported by UNIS, a. s.

References

[1] Hubík V., Švéda M., Singule V.: Mathematical model of a sensorless BLDC motor for aerospace actuators, In Modelling and Simulation MS 2008, Quebec City, Quebec, Canada: 2008, pp. 165–169, ISBN: 978-0-88986-741-3

[2] Hubík V., Toman J., Singule V.: BLDC motor control design in Matlab/Simulink, Zeszyty Problemowe – Maszyny Elektryczne, Vol. 2010, (2010), No. 88, pp. 35–39, ISSN 0239-3646

[3] RTCA/DO-178B: Software Considerations in Airborne Systems and Equipment Certification, RTCA, Inc.: USA, 1992

[4] RTCA/DO-254: Design Assurance Guidance for Airborne Electronic Hardware. FAA Advisory Circulars, AC No: 20-152, June 30, 2005

[5] RTCA/DO-160F: Environmental Conditions and Test Procedures for Airborne Equipment, RTCA, Inc.: USA, December 6, 2007

[6] Hubík V.; Švéda M.; Singule V.: On the development of BLDC motor control run-up algorithms for aerospace application, In Conference Proceedings, Poznan: 2008, pp. 1643–1647, ISBN: 978-1-4244-1742-1

Received in editor's office: May 5, 2011
Approved for publishing: July 1, 2011